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Investigations Into the Properties,
Conditions, and Effects of the Ionosphere

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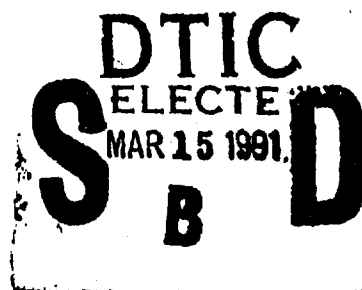
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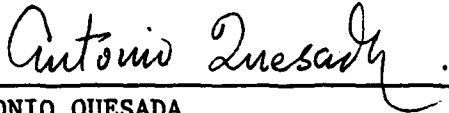
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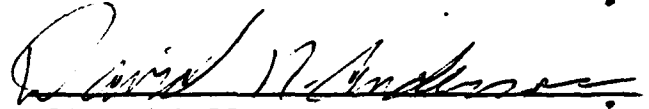


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<p>13. ABSTRACT (Maximum 200 words) Northwest Research Associates, as prime contractor, and its two subcontractors, Science Applications International Corp. and the University of Lowell Center for Atmospheric Research, supported GL/AFSC research in ionospheric physics and its systems effects over a period of three years under this hour-rate contract. Extramural and some intramural support was provided in the following six categories; laboratory measurements; field measurements, aircraft measurements; rocket, satellite, and Shuttle measurements; analytical and theoretical investigations; and engineering analysis. This report summarizes results, from work performed under 34 task requirement notices, on 15 specific topics. The 15 topics included ionospheric characteristics central to operation of HF systems, such as OTH radars; engineering studies of meteor-scatter communication links; effects on transionospheric radio propagation controlled by the "total electron content" (path integral of electron density) of the ionosphere and its fine structure (which produces radiowave scintillation); optical and ultraviolet (uv) effects of the aurora and airglow, as well as laboratory uv studies; and feasibility studies on modifying radio blackout and measuring electron-density in the D region.</p>				
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INVESTIGATIONS INTO THE PROPERTIES, CONDITIONS, AND EFFECTS OF THE IONOSPHERE

I. INTRODUCTION

This was an hour-rate contract under which Northwest Research Associates (NWRA), as prime contractor, and its two subcontractors, Science Applications International Corp. (SAIC) and the University of Lowell Center for Atmospheric Research (ULCAR), provided Members of their Technical Staffs (MTS) at negotiated hourly rates, with reimbursement of other direct and indirect costs, to conduct and support scientific and engineering investigations into the properties, conditions, and effects of the ionosphere. Specific work was carried out under individual Task Requirement Notices (TRNs) written for conduct and/or support of investigations in the following six categories: laboratory measurements; field measurements; aircraft measurements; rocket, balloon, shuttle, and satellite measurements; analytical and theoretical investigations; and scientific and engineering analysis.

II. ADMINISTRATIVE MATTERS

Work under a given TRN was authorized upon mailing to the contractor or subcontractor of a corresponding contract or subcontract modification following full-cycle approval thereof (by the Contracting Officer's Technical Representative; the contractor and, if appropriate, a subcontractor; and the Contracting Officer). Table 1 shows the administrative history of all TRN's issued under the contract. Tables 2(a), 2(b), 2(c), and 2(d) show the history of MTS expenditures for FY87, FY88, FY89, and FY90, respectively. Table 3 shows the history of expenditures for other direct and indirect costs (CLINS 4 and 5, including subcontract-administration costs).



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Table 1. TRN Administrative Information

	ORG	TITLE	DATE ARRIVED FROM GL	DATE SENT TO SUBCONTRACTOR	DATE RETURNED TO GL	DATE CONTRACT MODIFIED	END DATE
1	ULCAR	Meteor-Burst System Upgrade	12/21/86	12/22/86	12/30/86	1/12/87	2/24/87
2	ULCAR	Support for High-Latitude Ionosphere Research and OTH Test Support	1/12/87	1/13/87	1/17/87	2/4/87	9/30/87
3	SRUSAIC	Assessment of HF Configuration for Optimum Power Delivery	1/8/87	1/9/87(SRU)	WITHDRAWN		
4	Team	Technical Management & Administrative Support			WITHDRAWN		
5	SAIC	Radio-Blackout Modification Study	3/19/87	3/19/87	3/24/87	4/20/87	9/30/87
6	ULCAR/ NWRA	Meteor-Scatter Polar-Ionospheric Propagation Control-Systems Development and Data Analysis	2/9/87 3/20/87(rev)	2/9/87 3/23/87	2/17/87 3/24/87	4/20/87	9/30/87
7	SAIC	Investigation of D-Region Electron-Sampling Processes	2/9/87	2/9/87	2/17/87	3/20/87	9/30/87
8	Team	Studies and Technical Support	5/21/87	5/21/87	6/3/87	6/17/87	9/30/87
9	NWRA	Image-Processing Algorithm Development and Quick-Look Support	2/3/87	2/3/87	2/3/87	2/20/87	9/30/87
10	NWRA	Support for FY87 Midlatitude Electron-Density Calibration Campaign	4/23/87		4/23/87	6/4/87	9/30/87
11	ULCAR	Bermuda Ionosonde Tests in Support of OTH-B	5/15/87	5/15/87	5/21/87	6/17/87	9/30/87
12		Aircraft-mounted UV Camera			WITHDRAWN		

Table 1 (Continued). TRN Administrative Information

#	ORG	TITLE	DATE ARRIVED FROM GL	DATE SENT TO SUBCONTRACTOR	DATE RETURNED TO GL	DATE CONTRACT MODIFIED	END DATE
13	NWRA	Studies of Multipath Mitigation for TEC Measurements from GPS	5/21/87	-	5/21/87 & 6/3/87	6/17/87	9/30/87
14	NWRA	Transionospheric Scintillation & TEC studies	6/11/87	-	6/11/87	7/7/87	9/30/88
15	NWRA	Space-Radar Ionospheric Effects Studies	6/11/87	-	6/11/87	7/7/87	2/28/88
16	ULCAR	Meteor-Scatter Polar Ionospheric Propagation	11/9/87	11/9/87	11/13/87	12/4/87	1/31/88
17	SAIC	Investigation of D-Region Electron-Sampling Processes	11/19/87	11/20/87	11/23/87	12/22/87	6/22/88
18	SAIC	Feasibility of Radio-Blackout Modification	11/9/87	11/9/87	11/13/87	12/4/87	9/30/88
19	ULCAR	Meteor-Scatter Polar Ionospheric Propagation	11/9/87	11/9/87	11/9/87	11/16/87	12/31/87
20	ULCAR	Bermuda Ionosonde Tests in Support of OTH-B	10/28/87	10/28/87	10/28/87	11/2/87	3/15/88
21	ULCAR	Oblique Propagation Experiment and OTH-B Support	5/13/88	5/13/88	5/23/88	7/29/88	11/30/88
22	ULCAR	Advanced Topics in Space Environ- mental Forecasting Course	4/28/88	4/28/88	4/28/88	5/2/88	7/15/88
23	NWRA	Studies of Transionospheric Effects at Varying Latitude	5/13/88	5/13/88	5/23/88	7/27/88	9/30/88
24	ULCAR	Bermuda Sounder Tests and Over-the-Horizon (OTH) Radar Test Support	11/19/87	11/19/87	11/23/87	12/22/87	9/30/88

Table 1 (Continued). TRN Administrative Information

#	ORG	TITLE	DATE ARRIVED FROM GL	DATE SENT TO SUBCONTRACTOR	DATE RETURNED TO GL	DATE CONTRACT MODIFIED	END DATE
25	Team	Studies and Technical Support	11/9/87	11/9/87	11/13/87	12/4/87	9/30/88
26	NWRA	Image-Processing Algorithm Development & Data Management Support	11/9/87	11/9/87	11/9/87	12/4/87	9/30/88
27	SAIC	Investigation of D-Region Electron-Sampling Process	8/8/88	8/8/88	8/10/88	8/23/88	12/30/88
28	NWRA	AIRS Data Management and Mission Planning Support	7/22/88	-	7/22/88	7/27/88	9/30/88
29	NWRA	Studies of Ionospheric Electron-Content Processes	8/8/88	-	8/10/88	8/23/88	12/31/88
30	SAIC	Support for Studies of the Kinetics of Ultraviolet Emissions	11/15/88	11/15/88	11/16/88	12/5/88	9/30/89
31							
32	ULCAR	Oblique Propagation and OTH-B Support	2/2/89	2/2/89	2/3/89	2/23/89	9/30/89
33	NWRA	Image-Processing Algorithm Maintenance & Data-Management Support	11/18/88	-	11/18/88	12/5/88	9/30/89
34	NWRA	Studies of Ionospheric Effects During Solar Transition	12/7/88	-	12/7/88	12/13/88	9/30/89

Table 1 (Continued). TRN Administrative Information

#	ORG	TITLE	DATE ARRIVED FROM GL	DATE SENT TO SUBCONTRACTOR	DATE RETURNED TO GL	DATE CONTRACT MODIFIED	END DATE
35	NWRA	Studies on Implementation of an Optical-Disk Based System for Storage and Retrieval of Polar BEAR Data	4/17/89	-	4/17/89	5/5/89	11/30/89
36	SAIC	Investigation of D-Region Electron Sampling Processes	5/11/89	5/11/89	5/11/89	6/9/89	12/3/89
37	ULCAR	Sondrestrom Ionosphere Drift Measurements	5/11/89	5/11/89	5/11/89	7/6/89	9/30/89
38	NWRA	Studies of Ionospheric Effects Near Solar Maximum	9/15/89	-	9/19/89	9/22/89	12/3/89
39	NWRA/ ULCAR/ SAIC	Final Technical Report	3/26/90	3/38/90	3/30/90	4/9/90	7/3/90

III. SCIENTIFIC AND ENGINEERING STUDIES

We report in this section specific objectives of, activities relating to, results of, and conclusions reached as a result of the technical work conducted under this contract. Work under closely related TRNs has been grouped together. For each subject area, we identify the performing organization(s), TRN start and end dates, task Principal Investigators (P.I.s), and other participating personnel. All work has been reported in more detail in final reports on each TRN.

A. UPGRADE OF METEOR-SCATTER TEST CAPABILITY

Performing Organization: ULCAR

TRN 1: Meteor-burst System Upgrade

Dates: 12 January through 28 February 1987

Personnel: J.E. Powers and J.A. Weitzen

1. Objectives

The objectives of this TRN were to implement the capability of the Geophysics Laboratory of AFSC (GL) to analyze meteor-scatter test-bed data and to improve the operation of the meteor-scatter test bed in Greenland. These objectives were to be accomplished through the following tasks:

- a. Convert existing meteor-scatter analysis computer codes to ANSI standard Fortran format;
- b. Adapt the ANSI standard Fortran codes to run on the GL VAX and IBM-compatible Zenith Z-248 computers;
- c. Extend existing meteor-scatter analysis program for day-to-day throughput analysis as a function of time;
- d. Adapt existing meteor-scatter analysis program to run without manual waveform classification; and
- e. Develop a controller/transmitter interface for the Greenland meteor-scatter test bed. Interface to link HP85 computer with HP-3421A Controller and HP-8656B frequency synthesizer.

2. Activities

The initial task was to obtain the existing RADC software and convert it to ANSI standard Fortran 77 code. A complete listing of the program was delivered. The software that was obtained and modified included the software to create the blank databases, the software to classify meteor trails and identify the propagation mechanism automatically in each record, the routine to enter data into the databases, and the routines to access and analyze the databases. An

additional package of highly specialized routines to analyze the effects of a PCA event also was developed and delivered.

The second task was to transfer the code to both the GL VAX facility and the Z-248 PC at GL/LID. Several modifications to the existing code were required to implement the transportability. In order to implement the programs on the PC, we purchased a Microsoft F77 version 4.0 compiler for the PC.

The third and fourth tasks were to adapt and enhance the existing autoclassification software (Autoclass 1.5) so that it would run without operator intervention and would classify all data records. The autoclassification program is described in detail in RADC-TR-86-117 by Weitzen and Tolman. Autoclass was modified to classify all records and was tested using data obtained from RADC. Very satisfactory results were observed when the classifications of the program were compared to those of operators. Approximately 2000 records were analyzed, and the autoclassifier differed from the human classifier on less than five percent of the records. This difference included records in which the operator had erred. The fully automated autoclassification program has been given the name Autoclass 2.0.

The Autoclass program will be required to operate on data from the newly modified receiver at the Thule receiver site. The receiver was modified with a more narrow-band IF filter (3 kHz versus the 30 kHz previously used), reducing the background noise level by 10 dB from previous receivers. Several problems developed because of this modification, which greatly increased the number of meteors and made the data much more sensitive to background scatter. Adjustments to the processing heuristics are needed to adapt the autoclassifier to the changed environment.

Shakedown tests with about 2000 data records were performed on the complete software package. Results of both the autoclassifier and the database analysis were compared to corresponding data records. The results were very encouraging.

The final tasks were to design and develop the software-control programs and the hardware interface to allow programmable control of a meteor-burst transmitter system. The additional hardware required is a Hewlett-Packard Model 3421A Data Acquisition Control Unit, which replaces all of the existing control structure composed of electromechanical relays.

The design objectives included:

- Replacement of the electromechanical relay-control circuitry with a computer-controlled programmable system controller to allow for flexibility in field upgrades as the experimental requirements change;
- Retention of the text format of operational and error messages to minimize the need for operator training on the new controller;
- Retention of as much of the existing control circuitry as possible in the peripheral units to minimize wiring connections in field installation of the proposed interface;

- Incorporation of automatic time/date information provided by a time-code generator as the primary system clock source, retaining the internal HP-85B time clock as a secondary source;
- Addition of automatic monitoring of the three-phase main power-source voltages;
- Development of program code using the HP-Basic programming language to ensure compatibility with the system computer, an HP-85B; and
- Inclusion of automatic testing of the interface-control-bus status with an automatic bus reset-on-error feature.

The existing control program was analyzed to determine the functional command and status testing sequence. The resulting flowcharts then were used to redesign the program code, using the design objectives stated above as constraints.

One serious restriction was unavailability of the actual transmitter and the antenna-switching hardware. The output commands were simulated by switching resistive dividers, and the input status bits were simulated with bi-level voltages. The availability of the HP-3421A Control Unit and the HP-8656A signal synthesizer provided a reasonable mock-up to the actual system.

The control program was developed using information inferred from some earlier system-operation notes and the existing control program. The interface signal-conditioning requirements were developed in parallel with the code, as the hardware and software are highly interactive in this type of design.

A final test demonstration of the control program conducted at GL/LID indicated that all of the functional operations were correct and that all of the design objectives had been met. While the operation of all the command and status bits had been verified under simulated conditions, the true test was to await installation of the controller at the test-bed site. In the interim, a copy of the control program and the bit-simulator test jig had been provided to personnel at GL/LID for familiarization and further testing.

3. Results

Major upgrades to the high-latitude meteor-scatter test bed were completed. Software was converted to ANSI Standard 1977 Fortran and implemented on both the PC and the GL VAX. After some analysis, the GL VAX was selected for future data analysis.

A new automatic classification program, Autoclass 2.0, was written to remove operator intervention. An additional pass through the data was added to make decisions on the trails that could not be classified on the first two passes. New transmitter/controller software was developed for the HP-85.

B. SUPPORT FOR HIGH-LATITUDE RESEARCH AND TESTS OF THE OVER-THE-HORIZON BACKSCATTER (OTH-B) RADAR

Performing Organization: ULCAR

TRN 2: Support for High-latitude Ionosphere Research and OTH Test Support

Dates: 4 February through 30 September 1987

Personnel: D.F. Kitrosser, J.G. Moore, and B.W. Reinisch (P.I.)

1. Objectives

The objectives of this TRN were to support GL efforts during the Over-the-Horizon Backscatter Radar tests, including evaluation of selected radar functions, to provide analysis reports and radar studies, to upgrade existing GL systems for propagation/backscatter studies, and to improve data processing. These objectives were to be accomplished through the following tasks:

- a. Provision of a flight-qualified scientist to act as aircraft mission director, planning, coordinating, and reporting on a 250-hr flight program for OTH test support and the Polar Arcs campaign;
- b. Provision of flight engineering support for three ten-day campaigns of OTH test flights;
- c. Organizing, reducing, and archiving of aircraft and ground-based ionospheric data collected during the OTH test flights for subsequent analysis;
- d. Using the above database, characterize propagation conditions, assess frequency management, and evaluate performance of radar environmental-assessment software;
- e. Conduct of preventive maintenance and emergency repair of Goose Bay and Argentia Digisondes and related data-processing/communication equipment to ensure availability during OTH tests;
- f. Writing of a section on OTH-B radar operation for an OTH Handbook;
- g. Conduct of a study of specular scatter as a source of radar clutter for the central radar system;
- h. Upgrade of Goose Bay and Qaanaaq digisondes for oblique-propagation and directional/spectral studies; and
- i. Upgrade of GL digital data playback/processing capability.

2. Activities

The initial task under this TRN was to support the OTH test support and Polar Arcs campaign. During the period 10 February through 4 March 1987, the GL Airborne Ionospheric Observatory (AIO) supported the Polar Acceleration and Convection Studies (Polar ARCS). Mr. James G. Moore and Dr. Bodo W. Reinisch served respectively as the Mission Director and the Lead Engineer/Scientific Specialist for the on-board digisonde. The AIO served as the prime data source to support the planned launch of five instrumented rockets from the Sondre Stromfjord, Greenland, rocket range. Optical and ionospheric measurements from the AIO were used to determine the presence and location of subvisual or visual sun-aligned arcs, which were the requirements for rocket launch. Two rockets were launched successfully on 26 February 1987 -- a NASA/University of Alaska barium shaped charge and a GL instrumented rocket. Evaluation of the results indicated that data were acquired successfully. In addition, the AIO served as a target aircraft for tests of the OTH-B Radar. The location data from the AIO's inertial navigation system were reduced and provided to the OTH-B System Program Office for use in detailed radar-performance assessments. Thirteen flights were made in support of the Polar ARCS Campaign, and 58.4 flight hours were logged. The campaign was the first in which ULCAR served as Mission Director; planning and conduct of the campaign went smoothly, with all flight and scientific objectives achieved.

The second task was to provide flight engineering support to selected OTH test-flight campaigns. Under this TRN two flight campaigns, in addition to the flights identified above, were conducted.

The initial flight campaign was conducted during the period 23 April through 2 May 1987. The purpose of this campaign was to provide a dedicated aircraft target for calibration of the OTH target emulator at Argentia NAS and to collect ionospheric and propagation data for a database to be used in evaluation of the Environmental Assessment (EA) and Radar Control (RC) functions of the OTH radar. The campaign consisted of aircraft flights on 28 April and 1 May. The mission profile and data evaluation were reported in Interim Technical Report, "OTH-B Test Support Campaign No. 1," B. W. Reinisch *et al*, May 1987.

The second flight campaign was conducted during the period 15 October through 23 October 1987. The purpose of this campaign was to evaluate the effects of ionospheric heating or modification using the OTH radar. The campaign consisted of aircraft flights on 20 October and 22 October. The mission profile and data evaluation were reported in Interim Technical Report, "Over-the-Horizon Backscatter Radar Oblique Heating Experiment," G. S. Sales *et al*, December 1987.

The third and fourth tasks under this TRN were organization and evaluation of the ionospheric data collected during the OTH test flights. ULCAR established a database on the GL VAX for the purpose of data archiving and subsequent analysis. Evaluation of the emulator test data from the April-May 1987 flight campaign was conducted with respect to the OTH radar frequency-management and environmental-assessment software. Results of this evaluation were presented in Interim Technical Report, "Interim Analysis of Environmental Assessment Radar Operations during Test Flights," Gary S. Sales *et al*, November 1987.

The fifth task under this TRN was to provide maintenance support to the Goose Bay and Argentia digisondes. Under this TRN, two maintenance actions were required for the Argentia digisonde and one for the Goose Bay Digisonde.

The first maintenance call to Argentia involved failure of the 12- and 24-volt power supplies in the processor chassis and failure of the Okidata 92 printer. Both of these failures are thought to have been in direct response to a main power failure, which included a cable break at the transformer outside the trailer that houses the digisonde electronics. A receive antenna anomaly also was detected, but repair required outdoor work that was not possible during the heavy snow and high winds. Antenna Four was not switching between the O and X components, and Antenna Five showed low current readings.

The second maintenance call to Argentia was required to repair card #37, on which a wire had broken and lifted off the card. This wire connects components to the finger at the edge of the card. Card #65 of the antenna switch was repaired, and a defective coax cable connection was repaired to restore receive Antennas Four and Five to full operation.

One maintenance action was required for repair of the Goose Bay digisonde. Through remote consultation and support of the on-site (Marconi) personnel, the ten-watt power amplifier and the IBM-AT serial port were replaced and the defective units returned to the university for repair.

The sixth task under this TRN was development and submission of material for the OTH Handbook. Under this task, a section entitled "OTH Radar Operations/Propagation" was developed and submitted in February 1987.

The seventh task was to study specular scatter as a source of clutter for the central radar system. The results of this study were presented in Interim Technical Report, "The Effect of Equatorial Ionospheric Irregularities on the Performance of a South-looking OTH-B Radar," Gary S. Sales, October 1987.

3. Results

This TRN covered a variety of activities involving ionospheric measurements in support of the OTH program at high latitudes, where auroral effects are important. In general, we found that the use of the AIO flying in the radar coverage region is a very powerful tool to investigate propagation problems of the OTH radar. The flights served to evaluate the overall frequency-management performance of the EA operators; in general, they were doing a credible job.

We often tried to compare conversion of the measured f_oF_2 to the oblique frequency with the directly measured MOF from the radar site in Maine to the GL aircraft in the coverage area. The result is that it often was possible to use the vertical-incidence soundings to determine the actual MOF at a particular time and location. The most difficult problems arose whenever there appeared to be strong gradients in the F region of the ionosphere. Then the conversion was poor, and utility of the remote vertical-incidence soundings was limited.

The two campaigns designed to detect effects of the high-powered HF radar transmitters on the ionosphere were, inconclusive at best. The radar was made to "stare" in a fixed direction

while the GL aircraft flew in a confined pattern under this region. The power level was the largest used to date in the US to determine whether a system can modify the ionosphere near the reflection region, which was set to be over the Argentia Digisonde site in these cases. This was accomplished by frequency-managing the radar carefully. The results of the two campaigns were negative in that we could not detect any changes associated with turn-on and turn-off of the radar transmitters. The ionosphere was so disturbed at these high latitudes that the smaller heating effects easily could have been masked. The only conclusion was a recommendation to try this experiment again at a lower latitude using a different transmitter.

For all these campaigns, we have established a database stored at GL that can be used to evaluate the EA function of the OTH radar and its associated models.

TRN 21: Oblique-propagation Experiment and OTH-B Support

Dates: 29 July through 30 November 1988

Personnel: W.S. Kuklinski, J.G. Moore, B.W. Reinisch (P.I.), G.S. Sales, and J. Tang

1. Objectives

The objectives of this TRN were related to oblique propagation for provision of ionospheric data at locations not covered by the Air Weather Service DISS network. The great distances between some of the stations in the network produce gaps in the data that cannot be handled with the accuracies required by the ionospheric model being used by the OTH radar. Additional data provided by the oblique ionograms should increase the accuracy of the model output without additional stations being added to the network. Additional efforts under this TRN were to maintain and upgrade, when necessary, various digisondes operated for GL/LIS, OTH, and AFCC at selected sites, to analyze propagation data collected during OTH tests of the radar's environmental-assessment functions, and to complete inputs to an OTH handbook. These objectives were to be accomplished through the following tasks:

- a. Preparation of the Goose Bay ionosonde for oblique-propagation experiments, including addition of a transmit-antenna switch, provision of software that will automatically adjust the ionosonde clock based on time information from a precision time source to provide a time error of less than ten microseconds, and provision of a separate data-recording system for oblique-ionogram data;
- b. Preparation of a Digital Ionospheric Sounding System (DISS) for oblique propagation as described above and provision and installation, at a DISS site, of a transmit antenna suitable for the frequency range required for this experiment;
- c. Conduct of initial oblique-propagation experiments over a fourteen-day period to provide an oblique-ionogram database to be used in testing trace-identification algorithms;
- d. Development of automatic trace-identification algorithms and autoscaling software and testing them using the oblique-ionogram database;

- e. Provision and testing of alternative receive antennas at the University of Lowell field site to determine the ones most suitable for oblique-propagation reception;
- f. Reporting on the current status of the Automatic Real Time Ionogram Scaler (ARTIST) and improvement of the ARTIST software;
- g. Maintenance and upgrade of the digital ionosondes at Argentia, Newfoundland, and Goose Bay, Labrador and provision for emergency repair of these ionosondes as required for OTH test support;
- h. Maintenance and upgrade of the ionosonde at Qaanaaq, Greenland;
- i. Provision of data-analysis support and upgrading of data-playback system as required so that data taken at the various GL/LIS ionosondes are reduced within two months of arrival at GL. This was accomplished at GL using a government-furnished Zenith Z-248 computer with software provided by the contractor;
- j. Upgrade of the ARTIST computer at the Danish Meteorological Institute/GL Qaanaaq site to provide digisonde tape-playback capability for the station; and
- k. Provision of a backscatter-study description and completion of other inputs for the OTH Handbook.

2. Activities

The initial tasks under this TRN were to prepare the Goose Bay and Wallops Island DISS systems for establishing an oblique-propagation database. The Goose Bay DISS was modified during the period 10-15 August 1988. Modifications to the DISS included addition of a rubidium time standard and associated power supply and phase-lock card to the antenna-switch chassis, addition of a coaxial relay and control hardware to the exciter chassis, and addition of a second Pertec tape drive dedicated to recording oblique data. A successful oblique link was established between Goose Bay (transmit) and the University of Lowell Digisonde 256 located at Millstone Hill, Massachusetts (receiver). The Wallops Island, Virginia, DISS received the identical modifications during the period 9-16 September 1988. In addition to the modifications, ULCAR purchased and installed a Sabre MLP-4 80-foot-high rotatable log-periodic antenna (RLPA). A successful oblique link was established between Millstone Hill (transmit) and Wallops Island (receive), with Wallops Island receiving on the RLPA. The aforementioned oblique links were operated for a prolonged period to establish a sufficient oblique propagation database to support development and verification of the automatic trace identification algorithm and autoscaling software.

The fourth task under this TRN was to develop automatic trace-identification algorithms and autoscaling software using the oblique propagation database. The oblique-ionogram scaling algorithm was developed as a number of separate but interrelated functional operations, including noise/interference suppression, trace enhancement, trace identification, conversion

between scaled oblique-echo traces and the equivalent vertical midpoint echo traces, and echo-height inversion. The noise/interference suppression and trace-enhancement operations were developed to perform as a two-stage process utilizing a frequency-redundancy technique followed by an adaptive Weiner filter. The trace-identification algorithm then was developed to determine the most probable set of oblique-ionogram traces consistent with both these trace segments and additional information determined from vertical ionograms obtained at the receiving node of the oblique path. Details of algorithm development and projected developments were presented in Interim Technical Report, "Status of DORIS Automatic Scaling," Walter S. Kuklinski *et al*, October 1988 and Interim Technical Report, "Progress of DORIS Automatic Scaling," Walter S. Kuklinski *et al*, January 1989.

The fifth task under this TRN was to conduct investigations into improving receive-antenna designs. Preliminary studies were conducted to evaluate the frequency response of the turnstile loop antennas, using the Millstone Hill field site. Conclusive results were not obtained under this TRN; however, a new design was established under TRN 32.

The sixth task under this TRN was to report on the current ARTIST software and to make improvements. Evaluation of the DISS ARTIST software over more than two years operation at DISS field sites revealed that additional development efforts were required in three major areas: scaling and true-height profile analysis; automation of drift-data measurement and recording on magnetic tape; and input/output operations and diagnostic programs for testing of communication ports. Reporting on the status of ARTIST and associated improvements was provided in Interim Technical Report, "Status of ARTIST Upgrade," Jane Tang *et al*, September 1988 and Interim Technical Report, "Progress on ARTIST Improvements," Jane Tang *et al*, November 1988.

The seventh task under this TRN was to provide maintenance support to the Argentina Digisonde 256 and the Goose Bay DISS. During calendar year 1988, the Argentina Pertec tape drive had failed three times due to power surges. Under this TRN, ULCAR developed and installed a power-conditioning system at Argentina to protect the Processor and peripheral equipment from power surges. The Goose Bay DISS required modification to reduce RF interference to co-located HF equipments. Initial modifications were conducted to change the ten-watt and 100-watt solid-state amplifiers in the exciter chassis to DC via the standard pulsed configuration. Further evaluation required additional modifications to provide a blanking pulse from the DISS to the disturbed HF equipment. Implementation of these modifications reduced the interference to within acceptable limits for all systems.

The eighth task under this TRN was to upgrade the Qaanaaq, Greenland, Digisonde 256. During the period 3-12 December 1988, ULCAR installed, at the Qaanaaq site, upgrades to the antenna-switch chassis for improved high-frequency response and performance of the receive-antenna phase calibration.

The ninth and tenth tasks under this TRN were to provide data-analysis capabilities for GL, Hanscom AFB, Massachusetts, and for the Danish Meteorological Institute/GL, Qaanaaq, Greenland. Computer-based techniques were developed to edit and display the ionospheric data collected in the ARTIST format automatically and interactively. These techniques provide daily

and monthly data summaries in ionospheric-characteristic and true-height formats. Under this TRN, these computer-based techniques were presented and made available for use on the government Zenith Z-248 computers by GL personnel. In addition, ULCAR provided the Danish Meteorological Institute in Qaanaaq the capability, using off-line ARTIST, to play back digisonde data stored on the digisonde tape recorder.

The final task under this TRN was to provide a backscatter study write-up and other inputs for the OTH Handbook. This task was accomplished with the submission of the Interim Technical Report, "Over-the-Horizon Backscatter (OTH-B) Radar System," Gary S. Sales, April 1989.

3. Results

A database to be used for development of automatic scaling and inversion of oblique ionograms was obtained over several long paths. These long-path data were necessary to supplement the existing data, which involve paths under 800 km. It became clear that the existing algorithms were not satisfactory for the longer-path data, primarily because the end-point vertical-ionogram-based trace-identification algorithm was not adequate for these longer paths.

The Weiner-filtering noise-clearing and trace-enhancement method performs well on a wide range of oblique ionograms. Some questions remain, however on robustness of these algorithms for an operational system.

Finally, special displays of simulated backscatter ionograms were produced under this TRN as part of the handbook preparation. These simulations were run for azimuths running from 16.5° T through 196.5° T, corresponding to the coverage of the ECRS. They were generated for six times of the day and for three sunspot numbers, representing low, medium, and high levels of solar activity. The ionospheric model used here was IONCAP from ITS, which we modified to improve the F₁-region behavior. The handbook contributions will make the job of the EA operators at their radar sites easier.

TRN 32: Oblique-propagation and OTH-B Support

Dates: 23 February through 30 September 1989

Personnel: G. Crowley, D.F. Kitrosser, W.S. Kuklinski, J.G. Moore, B.W. Reinisch (P.I.), and G.S. Sales

1. Objectives

The objectives of this TRN were to provide scientific and technical manpower for airborne test support of the east coast OTH-B radar system and to support evaluation of the radar's EA and CR functions; to support the deployment, maintenance and emergency repair of ionosondes important to OTH and GL efforts and the improvement of analysis software resident in the ionosonde computers (ARTIST); to advance the DORIS program for monitoring the ionosphere; and to provide the basis for a go/no-go decision on the program. These objectives were to be accomplished through the following tasks:

- a. Provision of a flight-qualified scientist to act as aircraft mission director for planning, coordinating, and reporting on flight programs for the OTH-B test support and scientific aircraft campaigns;
- b. Provision of flight scientific and engineering support for OTH-B and scientific aircraft campaigns;
- c. Organization, reduction, and archiving of aircraft- and ground-based ionospheric data collected during OTH-B test flights for subsequent scientific analysis;
- d. Use of the above database, characterization of propagation conditions, assessment of frequency management, and evaluation of radar environmental-assessment software and frequency management;
- e. Maintenance of the Argentia, Newfoundland, DISS for the OTH/DORIS test program;
- f. Maintenance and upgrade, as necessary, of the Digisonde 256 located at Qaanaaq, Greenland, for use as part of the Air Weather Service (AWS) DISS;
- g. Installation and maintenance of a DISS system at a field site operated by the Danish Meteorological Institute near the Sondre Stromfjord incoherent-scatter radar facility;
- h. Analysis, as required, of data taken at the various GL/LIS field sites, and upgrade of the data-playback system as required. This was accomplished using the digital ionosonde data processor located at GL;
- i. Conduct of oblique-propagation measurements between Goose Bay, Wallops Island, and Millstone Hill to establish the necessary database;
- j. Development of automatic methods for synchronizing any two cooperating DISS and for measuring the absolute group delay of signals propagating between two sites with accuracies required for remote sensing; and
- k. Preparation of material for a DORIS program "go/no-go" decision.

2. Activities

The initial four tasks under this TRN were to provide flight-qualified personnel in support of the GL AIO and subsequent data archiving, reduction, and analysis. Under this TRN, two flight campaigns were conducted: OTH-B Radar Program test support during the period 1-9 March 1989 and OTH-B Radar Program test support and scientific flight campaign during the period 2-28 October 1989. Details of the March 1989 flight were reported in Interim Technical Report, "Test Flight Report 1 March 1989 to 9 March 1989," James G. Moore, May 1989. Scientific analysis of the various data collected during the March flights in reference to the performance of the OTH-B radar environmental-assessment software and frequency management was presented in Interim Technical Report, "Investigation of the Effects of the

High Latitude Ionosphere on OTH Target Detectability," Gary S. Sales *et al*, August 1989. Due to program delays, the second flight program was conducted after conclusion of this TRN; however, a summary of the flight profile and data analysis was presented in Interim Technical Report, "Analysis of Ionospheric and Propagation Data Collected During Testing of the East Coast OTH-B Radar System," James G. Moore *et al*, March 1990.

The fifth task under this TRN was to maintain the Argentia Digisonde 256 for the OTH/DORIS program. During the period 26 February 1989 through 3 March 1989, two ULCAR personnel were on site to conduct periodic maintenance, conduct receive-antenna phase calibration, and establish an oblique propagation link between the Goose Bay DISS and Argentia Digisonde 256. Successful oblique links were established for the period 1-2 March 1989. The DORIS hardware modifications performed on the DISS units at Goose Bay and Wallops Island were not performed on the Argentia Digisonde 256. Synchronization between Argentia and Goose Bay was accomplished manually via telephone communications between the two sites.

The sixth task under this TRN was to maintain and upgrade the Digisonde 256 located at Qaanaaq, Greenland to become part of the AWS DISS network. During the performance of this TRN, the Qaanaaq Digisonde 256 did not require any maintenance actions.

The seventh task under this TRN was to support the initial deployment of a DISS system near the incoherent-scatter radar facility located at Sondre Stromfjord, Greenland. During the period 8-16 June 1989, two ULCAR personnel were on site to assist GL personnel with initial deployment and system checkout of the DISS system. The initial deployment of the DISS system consisted of unpacking, assembling, and positioning the receive-antenna array and interconnecting the DISS system. The system checkout consisted of system initialization, updating the antenna-switch chassis for improved high-frequency response, and phase calibration of the receive antennas. On departure of the ULCAR personnel, the DISS system used a dipole antenna temporarily until movement of the rhombic antenna to the field site was accomplished. The rhombic antenna was relocated to the designated site the following week by GL personnel, who connected the rhombic to the DISS system and verified proper operation.

The eighth task under this TRN was to provide data-analysis support to GL as required. This task was accomplished with the delivery and follow-on training of the ARTIST Data Editing and Printing (ADEP) system. The ADEP system is a stand-alone PC-controlled system capable of ARTIST data playback and editing.

The final four tasks under this TRN were to perform oblique-propagation measurements, establish methods to synchronize automatically any two cooperating DISS systems, further development of the automatic trace-identification algorithms and autoscaling software, and provide inputs for a go/no-go DORIS program decision. Details of these efforts were presented in Interim Technical Report, "Automation of Oblique Propagation Measurements, Oblique Trace Identification and Inversion," Walter S. Kuklinski *et al*, January 1990.

3. Results

For this task, a major effort was made to establish a database that will serve for assessment of the ECRS frequency-management and coordinate-registration functions. Every

effort was put forth to make this database, including magnetic tapes from the radar itself, as complete as possible. This material will serve as the basis of a follow-on effort to improve the ionospheric models that are an integral part of the radar system.

For the DORIS part of this task, we found that the echo-trace algorithm was able reliably to determine the leading edge points on data obtained over a wide range of conditions and path lengths. The iterative Newton-Raphson technique for the quasi-parabolic electron-density model was adequate for only a limited number of ionograms. To make a substantial improvement in reliability of the inversion technique will require utilization of a "simulated annealing" optimization algorithm.

C. FEASIBILITY OF MODIFYING RADIO BLACKOUT

Performing Organization: SAIC

TRN 5: Feasibility of Radio-blackout Modification

Dates: 20 April through 30 September 1987

Personnel: C.L. Chang, D. Rault, and E. Szuszczewicz (P.I.)

TRN 18: Feasibility of Radio-blackout Modification

Dates: 4 December 1987 through 30 September 1988

Personnel: D. Rault, E. Szuszczewicz (P.I.), and G. Earle

1. Objectives

The objective of TRN 5 was to determine suitable chemicals whose release from a reentry vehicle would eliminate radio-frequency blackout during reentry, and that of TRN 18 was to determine the chemical to be flown on NASA AOTV/AFE, in support of the PS-28 Project Forecast II initiative.

2. Activities

SAIC developed a new numerical tool to investigate the feasibility of mitigating radio blackout around the AOTV/AFE by injecting electrophilic gases into the vehicle wake. In most of the braking phase of the AFE, the ambient gas density in the near wake of the vehicle is so low that standard fluid codes are not applicable. Therefore, SAIC developed and used the Rarefied Aerodynamic Characteristics Evaluator (RACE) code, designed specifically to simulate flows in the transition and free-molecular-flow regimes for multispecies gases, with and without chemical reactions, and internal energy transfer. RACE is based on the direct simulation Monte Carlo method developed by G. Bird.

In RACE, the gas dynamics and flowfield properties were evaluated by considering a relatively small sample of real gas molecules and tracking each selected molecule as it collides with other gas molecules and the vehicle walls. Such a molecular approach was necessary since, at low gas densities, intermolecular collisions are too infrequent to maintain the gas in Maxwellian equilibrium; consequently, macroscopic properties such as temperature and pressure

cannot be defined uniquely. Furthermore, at low densities the fluid conservation equations break down and can no longer be used in the simulation of flowfields.

3. Conclusions

The first goal of the SAIC application of RACE to the blackout problem was accomplished by the code's reliable prediction of the fundamental features of supersonic wake flows, characterized in the continuum flow regime by a large recirculation region, a wake shock, a free shear layer, and a lip shock. At the low gas densities considered in SAIC's simulation, these features were not as evident as in the high-density continuum-flow regime; the shocks were weak and very diffuse, the recirculation zone was very small and confined to the near vicinity of the vehicle base wall, and the shear layer was thick and diffuse.

The second objective was to determine the effective distribution of an electrophilic injection (e.g., SF_6) in the near-wake flowfield and to obtain a first qualitative estimate of the "diffusion" of the electrophilic gas into the wake flowfield. In comparing two different injection rates based on the SF_6 /air-density ratio in the wake of a 2-D rectangular step simulator of the AFE geometry, it was demonstrated that injected SF_6 would completely destroy the vortical motion of the air and would barely penetrate into the high-velocity air stream. It was expected, therefore, that the wake region of the AFE effectively could be purged of electrons by wake injection of SF_6 , thus allowing for possible communication links between the spacecraft and ground control during reentry.

D. DATA-ACQUISITION AND ANALYSIS TOOLS FOR STUDIES OF HF AND METEOR-SCATTER PROPAGATION IN POLAR REGIONS

Performing Organizations: ULCAR and NWRA

TRN 6: Meteor-scatter Polar-ionospheric Propagation Control-systems Development and Data Analysis

Dates: 20 April through 30 September 1987

Personnel: C.C. Andreasen (NWRA), E. Li (ULCAR), J.E. Powers (co-P.I.) (ULCAR), and J.A. Weitzen (co-P.I.) (ULCAR)

1. Objectives

The objectives of this TRN were to support GL studies of HF and meteor-scatter propagation effects under severely disturbed ionospheric conditions through the development, implementation, and operation of data acquisition and analysis techniques and tools. These objectives were to be accomplished through the following tasks:

- a. Development of PC controller software and interface hardware for polar-cap meteor-scatter receiver/data-acquisition systems;
- b. Implementation of control and interface systems for data acquisition and analysis at Thule AB and Sondrestrom AB, Greenland; and

- c. Enhancement and adaptation of acquisition systems to meet project needs.

2. Activities

Under this TRN, ULCAR provided support to the GL high-latitude meteor-scatter test bed, which included improving the software of the transmitter-control program at Sondre Stromfjord, Greenland, a thorough laboratory checkout of backup receiver unit #2, testing of the software for the new synchronous receiver, and an on-site visit to Thule, Greenland.

Two days were spent in Sondre Stromfjord to assess the status of the transmitter-control software. Software improvements were made that provide for proper frequency switching after a manual change is made to the system clock, operation of the overload diagnostic routine, and readings of the incident and reflected power.

Software for the new synchronous receiver was modified and tested on a Zenith Z-248 computer. The data-acquisition card (DASH-16) was tested with an appropriate software driver to simulate the operation of the new meteor-burst receive system. Simulated data storage was tested for the 1/4-inch tape backup unit.

During the visit to Thule, the primary receiver unit was found to be unstable. Troubleshooting of the primary receiver was hampered by the lack of a card extender. Backup receiver unit #1 was repaired, installed, and used for routine data acquisition. Repairs included elimination of faulty connections in an impedance-matching coil and a decoupling capacitor of the front-end IF strip. After the faulty connections were eliminated, the dynamic range of the IF strip improved by 20 dB. Noise measurements at the three transmitter frequencies and the receiver-noise baseline were found to be stable. A partial alignment of the receiver system was also conducted. A fiber-optic line was installed for control of GL's Meteor Communication Corporation (MCC) full duplex 65-67 MHz system between Thule and Sondre Stromfjord. The control signals were to prevent simultaneous operation of the MCC system and the high-latitude meteor-scatter test bed.

Support was provided to establish a 45-MHz meteor-scatter link between Thule and Nord, Greenland. The two-kilowatt transmitter was checked and determined to have a faulty exciter. A replacement exciter was supplied to complete the laboratory testing and to serve as a backup. The primary unit was found to have a poor solder contact in the preamplifier and faulty power transistors in the 100-watt amplifier. These problems were corrected, and the transmitter operated successfully. The August trip to Thule led to establishment of a temporary link to Nord. This 45-MHz link operated for one week using the repaired two-kilowatt transmitter, the new synchronous receiver, and a Yagi transmit antenna mounted on top of the MCC transmit mast. The control signals for the MCC system were used to operate the temporary 45-MHz link from Thule to Nord.

3. Results and Conclusion

Under this TRN, development of a new data-acquisition system began. The bandwidth of the receiver was reduced from 3000 Hz to 100 Hz to provide greater resolution of weak trails.

The new software allowed continuous recording of long-duration waveforms and marked a major improvement over the previous HP-85-based system.

E. CALIBRATION OF D-REGION ELECTRON-DENSITY MEASUREMENTS

Performing Organization: SAIC

TRN 7: Investigation of D-region Electron-sampling Process

Dates: 20 March through 30 September 1987

Personnel: C.L. Chang, D. Rault, and E. Szuszczewicz (P.I.)

TRN 17: Investigation of D-region Electron-sampling Process

Dates: 22 December 1987 through 22 June 1988

Personnel: C.L. Chang, G. Earle, D. Rault, and E. Szuszczewicz (P.I.)

TRN 27: Investigation of D-region Electron-sampling Process

Dates: 23 August through 30 December 1988

Personnel: C.L. Chang, D. Rault, and E. Szuszczewicz (P.I.)

TRN 36: Investigation of D-region Electron-sampling Process

Dates: 9 June through 3 December 1989

Personnel: C.L. Chang, D. Rault, and E. Szuszczewicz (P.I.)

1. Objective

The objective of these TRNs was to calibrate flight instrumentation for making measurements of lower-ionospheric conductivity.

2. Activities

A three-phase effort supported the GL/LID activities to measure *in situ* the free-electron population in the 40-85 km altitude regime. Exploring a species-conversion technique and parachute-borne mass spectrometer sampling technique, the first phase of the study focused on design of the detection scheme and development of appropriate models from which to extract ambient charged-particle densities from the measurements. The second phase focused on an analysis of the data, its interpretation relative to instrument performance and ambient-particle densities, and comparison of the observations with model predictions. Phase Three dealt with two separate laboratory-simulation studies of a flight experiment designed to measure the free-electron number-density profile in the earth's mesosphere.

Phase One

The approach in Phase One was two-fold, leading to recommendations for a front-end design and for ion sampling and SF₆ injection. The 1-D ion-flux-cell design focused on a pillbox geometry with a 2" height and the maximum diameter allowable in the launch vehicle

configuration. Other design drivers included a guard electrode for the aperture plate and controllable potentials to the injector plate. Design guidelines also included the measurement capability of bipolar currents at the injector surface and the aperture plate. To minimize dielectric charging on active surfaces, all electrode surfaces were to be gold plated.

Relative to SF_6 injection and ion sampling, the following recommendations were made: (1) that ion sampling begin on the upleg portion of the trajectory before SF_6 injection was initiated, the preferred mode to involve delay of SF_6 injection until apogee; (2) that the ion-sampling format be based on a "minimum mass spectrum requirement;" (3) that voltage differences between the injector and the aperture plate not exceed an absolute value of 2 volts; and (4) that the injector plate be operated at the local plasma potential.

Since the payload preparation and launch schedule did not allow time to prepare the electronics to track the local plasma potential and apply appropriate voltage levels to the injector plate, an approach was adopted to apply several levels of voltage to the injector and plan for post-flight analysis to determine the values and conditions under which the injector was at or closest to the local plasma potential. GL/LID selected -5, -1, -.5, 0, +.5, and +1 volts for the positive-ion collection mode and -1, -.5, 0, +.5, +1 and +5 volts for the negative-ion collection mode.

With zero field penetration assumed in Region 1, analysis focused on flowfield effects on the transport of charge from the ambient environment to the injector surface. While the numerical flowfield simulation included Region 2 (i.e., the domain within the 1-D cell), initial emphasis in the simulation focused on the flowfield input to the 1-D cell and the use of those results as an input boundary condition for a Particle-in-Cell (PIC) code, which calculated the transport of all charged species from the injector plate to the mass-spectrometer aperture. The PIC code was designed to include flowfield collisionality and electric-field effects.

Phase Two

The second phase focused on an analysis of the data, its interpretation relative to instrument performance and ambient particle densities, and comparison of the observation with model predictions. A rocket-borne mass spectrometer was launched by GL/LID at Wallops Island, VA, to an 86-km apogee. Parachute deployment and ion sampling were initiated on the upleg trajectory, with mission emphasis on ion sampling in the altitude range 75-45 km on the down leg. The sensor was a quadrupole ion mass spectrometer capable of positive and negative ion sampling modes. Its aperture plate was flush mounted with the forward surface of the main payload body. Forward of the aperture plate was a charged-particle flow-control cell (called a 1-D ion-flux cell) designed to confine charged-particle motion to one dimension by the application of bias potentials to a parallel-plate geometry. The ion-flux cell had a forward injector "plate" constructed from an open helix with 0.008" holes for forward injection of SF_6 .

The approach to N_e measurement was based on the conjecture that the ambient free electron population will be related directly to the induced negative-ion population (i.e., SF_6^-) because of its rapid attachment to SF_6 . Collisionality, heavy-particle fractionation, neutral SF_6 distribution, negative-ion attachment time, flowfield effects, and electric-field collection efficiencies all

contribute to the exact relationship between the free-electron density and the sampled negative-ion distribution. The overall SAIC task involved: (1) design of the front-end sampling technique; (2) development of a first-principles model that predicts the relationship between measured values of SF_6 and the ambient free-electron population; (3) development of concepts and designs for direct N_e measurement techniques; and (4) adaptation of the SAIC plasma facility for flight simulations.

Phase Three

The Phase-three laboratory simulations used a laboratory-plasma vacuum chamber specially configured to simulate the flight parameters. The first simulation tested the "original" 1-D ion-flux-cell design, while the second tested a redesigned gas injector, in order to determine whether the reconfiguration would allow the electron-density measurements to be made successfully. The first simulation study was performed after the initial flight experiment and revealed a tendency for a region of space charge to form in front of the mass spectrometer's aperture during a flight. This laboratory result suggested that space-charge buildup adversely affected the flow of negative ions to the aperture of the mass spectrometer during the flight so that the electron content could not be determined from the flight data. The redesigned injector constituted an attempt to eliminate this problem.

3. Results

The primary result of activity in Phase One was measurement of the free-electron population through the injection of an electrophilic (SF_6), with subsequent attachment of an electron and mass-spectrometer sampling of SF_6 . The key to integrity of this technique rested in a complete understanding of the transfer efficiency of the undisturbed charged-particle distributions across sub- and supersonic flowfield boundaries, the electron-gettering efficiencies of the injected SF_6 , and the electric-field and flowfield controls of charged-particle transport in the 1-D ion flux cell.

The phenomenological domains involved in the transfer efficiency were studied in detail. Region 1 was modelled with an axisymmetric continuum flowfield code that provided detailed profiles of particle densities, velocities, and normalized fluxes corresponding to the actual flight conditions that prevailed during the GL experiment in August 1987. Efforts were focused on the flux-density transfer efficiency from the undisturbed medium to the injector plane and the current collection characteristics of the injector helicoil. An analysis of the collected currents and their interpretation through the modelled flowfield characteristics provided altitude profiles of total positive and negative ion densities and the densities of the free-electron population. The results were compared with modelled charged-particle density profiles and were found to be in excellent agreement. The agreement between the modelled and measured values of positive and negative ion densities was of a quality beyond expectations. The measured values were orders of magnitude below those predicted by the mesospheric/stratospheric models. This difference was a consequence of the SF_6 electron-gettering efficiency and provides evidence for its proper operation during flight.

Detailed particle-in-cell calculations of charged-particle flow from the injector plane to the mass-spectrometer aperture were made. The code accounted for electric- and flowfield forces, and clearly showed the altitude-dependent dominance of collisional terms over attracting and repelling electric fields. Attention was focused also on the mass-spectrometer results for integrated counts ($M > 10$ amu) of attracted and repelled species for varying applied potentials. At altitudes above 80 km, electric fields clearly were observed to play a role in ion discrimination, but at lower altitudes there were no observed electric-field effects.

The laboratory simulations of the 1-D flux-cell geometry provided evidence of anomalous space-charge effects within the cell that interfered with the polarity control of charge collection and sampling of the parachute-borne ion mass spectrometer. These laboratory results corroborated the performance of the in-flight experiment and suggested the need for a sensor head front-end redesign. The redesign was tested in the second part of the laboratory simulations, with results pointing to uniform and intuitively satisfying electric-field distributions in the upstream far-field regime. Measurements in the near field suggested anomalous potential distributions in the presence of SF_6 injection, pointing to the sensitivity of "in-situ" measurement techniques to surface contamination effects in high-density environments involving exotic gases.

F. PLANNING AND TECHNICAL SUPPORT

Performing Organizations: NWRA, SAIC, and ULCAR

TRN 8: Studies and Technical Support

Dates: 17 June 1987 through 30 September 1987

Personnel: E.J. Fremouw (P.I.)(NWRA), B.W. Reinisch (ULCAR), and E. Szuszczewicz (SAIC)

TRN 25: Studies and Technical Support

Dates: 4 December 1987 through 30 September 1988

Personnel: E.J. Fremouw (P.I.)(NWRA), B.W. Reinisch (ULCAR), and E. Szuszczewicz (SAIC)

1. Objective

The objective of these TRNs was to provide efficient and effective program planning directed toward ionospheric-effects problems faced by the Air Force. This objective was to be accomplished through the following task:

- Provision of studies and support to the Ionospheric Physics Division on technical tasks to include ionospheric propagation, experimental program planning, and high-latitude auroral effects.

2. Activities

Activities under these TRNs were two-fold. First, occasional meetings were held between GL and contractor personnel to define priorities and to identify candidate TRNs needed to meet the overall goals of the contract. Second, quarterly and annual reports summarizing work performed under the contract during FY87 and FY88 were prepared. No such TRN was issued to fund such activities during FY89, although quarterly reports still were required under the contract and were provided.

3. Results

Critical scientific and technical planning was provided in support of various GL activities, including high-latitude meteor-scatter, D-region electron-density sampling, OTH-B tests, space-based radar studies, and measurements of TEC using GPS. Under these TRNs, the contract team supported GL in technical meetings to define various technical objectives, resources required, and demonstrable milestones.

As an example, evaluation of OTH-B radar test planning showed a need for a 150-hour flight-test program in FY89. The AIO was to be used as a dedicated target for the OTH-B radar test programs and would also provide ionospheric and propagation data to assess environmental impacts on the radar performance and operation. In addition, an ULCAR representative provided a briefing to Lt. Gen. A. Casey, SD/CC, for the purpose of outlining GL support to the OTH-B Radar Program and to answer technical questions.

G. ULTRAVIOLET IMAGING AND SPECTROPHOTOMETRY OF THE AURORA AND AIRGLOW

Performing Organization: NWRA

TRN 9: Image-processing Algorithm Development and Quick-look Support

Dates: 20 February through 30 September 1987

Personnel: F.J. LeBlanc, R.D. Lucas (P.I.), I. Oznovitch, R.E. Robins, and N.W. Rosenberg

TRN 10: Support for FY87 Midlatitude Electron-density Calibration Campaign

Dates: 4 June through 30 September 1987

Personnel: D.B. Keir, J.M. Lansinger (P.I.)

TRN 26: Image-processing Algorithm Development and Data-management Support

Dates: 4 December 1987 through 30 September 1988

Personnel: R.M. Bussey, D.F. Collins, E.J. Fremouw, F.J. LeBlanc, J.M. Lansinger, R.D. Lucas (P.I.), I. Oznovitch, L.A. Reinleitner, N.W. Rosenberg, J.A. Secan

TRN 28: AIRS Data Management and Mission-planning Support

Dates: 27 July through 30 September 1988

Personnel: C.C. Andreasen, E.J. Fremouw, J.M. Lansinger (P.I.)

TRN 33: Image-processing Algorithm Maintenance and Data-management Support

Dates: 5 December 1988 through 30 September 1989

Personnel: R.M. Bussey (P.I.), F.J. LeBlanc

1. Objectives

The objectives of these TRNs were to aid GL/LIU in collecting and processing data from the AIRS imager on board the Polar BEAR satellite and in deriving useful products therefrom in a timely manner.

2. Activities

Under TRNs 10 and 28, NWRA deployed and operated the Defense Nuclear Agency (DNA) transportable satellite beacon and telemetry receiver, "Rover," at Hanscom Field, MA, and at Kwajalein, Marshall Islands to assist GL/LIU in collecting data from the Auroral Ionospheric Remote Sensor (AIRS) on board the Polar BEacon And Remote Sensing (Polar BEAR) satellite. Under TRNs 9, 26, and 33, NWRA developed and refined algorithms for geometric and spectrophotometric processing of AIRS data collected by means of Rover and by means of fixed receivers located at Tromso, Norway; Sondre Stromfjord, Greenland; and Churchill, Manitoba. NWRA also assisted GL/LIU in the processing, management, and use of data from AIRS and from other ultraviolet sensors carried on earlier satellites.

In addition to work with AIRS data, NWRA also aided GL/LIU personnel in the management and application of data from S3-4 and in preparations for the Horizon Ultraviolet Program (HUP) carried out on the Space Shuttle. Specifically, S3-4 data were employed to refine the earth-background radiation curve published in the GL(SFSC) Handbook of Geophysics and the Space Environment. NWRA personnel participated in a training meeting during the third quarter of 1988 to familiarize Shuttle astronauts and NASA and Lockheed engineers with the construction and operation of the HUP instrument. Finally, NWRA participated in planning for the Atmospheric Ultraviolet Radiance Analyzer (AURA), which has been proposed for further development of techniques to determine electron-density profiles, for investigation of ionospheric regions producing radiowave scintillation, and for location and characterization the auroral oval.

3. Results and Conclusions

One of the applications of AIRS data is an attempt to produce ionospheric electron-density profiles from remote passive topside sensing. Development of this procedure required real-time acquisition of AIRS data simultaneously and closely co-located with data from an incoherent-scatter radar. The field procedure to accomplish such acquisition employed Rover at Hanscom, with the radar located at Millstone Hill, MA, providing "ground-truth" information on ionospheric electron-density profiles and measurements of electron and ion temperature, plasma drift, and the thermospheric neutral wind during selected satellite passes between 1 July and 7 August 1987. NWRA later deployed Rover to Kwajalein to collect daytime and nighttime data from AIRS and other Polar BEAR instruments both during quiet times and at times during which

radiowave propagation through the equatorial ionosphere was disturbed by scattering in plasma-density irregularities. That excursion took place in July and August of 1988 in conjunction with DNA's Propagation Effects Assessment at Kwajalein (PEAK 88).

Any use of AIRS data must account for pitch, roll, and yaw of the Polar BEAR spacecraft. Ordinarily, attitude estimates are derived from measurements and models of solar and magnetic-field direction, but the AIRS database contains gaps in the required measurements. Our attitude-correction algorithms employ the measurements when they are available and exploit the signature of the earth's limb when they are not. In some images, both limbs are visible, and they indicate a height of approximately 150 km for the emitting layer. Based on these observations, we developed a program, ROLADJ, that computes the roll required to place the layer at that altitude when a limb signature is available.

Once satellite attitude and other distortions are accounted for, satellite imagery may be projected onto arbitrary map coordinates for morphological analyses and correlative studies involving concurrent data from multiple sensors. Toward this end, we developed software that permits presentation of AIRS data from any receiver on geographic coordinates, for comparison with all-sky camera images, radar and radio-beacon data, and other relevant spatial measurements. Our approach was rigorous in that arbitrary satellite motions are accounted for, and exact principles of geometry are used throughout. The image restoration corrects for the geometric distortions inherent in mirror-scan imaging, as well as that stemming from spacecraft attitude. The floating-point-intensive geometry calculations are performed on an arbitrary (adjustable) reference grid, which can be coarse for quick-look purposes or fine for higher accuracy. The software was implemented for use on an AT-compatible computer.

AIRS provided simultaneous records from three detectors. Count rates usually were low, so the data are best treated as a Poisson process. The errors stemming from the low count rate can be reduced by accumulating counts, effectively trading spatial resolution for a statistically acceptable error. We developed a program, FILTRAW, that provides the necessary tradeoff at each point in an image while preserving the original percentile distribution.

To facilitate separation of auroral and airglow emissions, we developed a program, GEOMLSQ, for normalizing the latter, based on column path-length and solar flux. The program finds the dependence of the count on a power of path-length and on a power of solar flux, the latter taken as proportional to the sine of the solar elevation angle.

The relative morphology of auroral forms in two wavelength bands may be shown most clearly after histogram equalization. For this purpose, we developed Program HISEQ, which equalizes the overall apparent intensity in the two bands while preserving relative spatial variations in the intensity of each. We then developed Program MULBND, which permits co-display of the two bands, one in red and the other in green. Where the two bands match in their relative intensity, a yellow image of suitable intensity is displayed. Elsewhere, a tendency to red or green is displayed, again with an intensity representing the local intensity of the auroral form. From such displays, one can discern differences between the locations of different emitting species.

Under TRN 26, a large effort was made in processing and organizing AIRS and S3-4 data. This involved about 1000 processed data files, 300 Megabytes of disk space in a MicroVAX computer, and about 270 floppy disks. The raw data files were saved and backed up on magnetic tape. Using NWRA programs, about 500 false-color images of the auroral oval were photographed.

Under TRN 33, we compared data from the HUP database between 200 and 290 nm with predictions from a pre-release version of the LOW-resolution radiance and TRANsmission (LOWTRAN 7) model. The LOWTRAN code has been extended in Version 7 for use at ultra-violet wavelengths by addition of new absorption crosssections for ozone and molecular oxygen, plus solar irradiance at 0.15-nm resolution and a multiple-scattering algorithm. Agreement between LOWTRAN 7 and the HUP data for nadir viewing and low solar zenith angles is excellent. The code also is in excellent agreement with S3-4 measurements of radiance levels and spectral variability in the daytime at middle latitudes. There are differences at twilight, and we suggest that addition of airglow and fluorescence sources to the model would improve its fidelity.

H. IONOSONDE TESTS IN SUPPORT OF OTH-B SECTOR-THREE OPERATIONS

Performing Organization: ULCAR

TRN 11: Bermuda Ionosonde Tests in Support of OTH-B

Dates: 17 June through 30 September 1987

Personnel: D.F. Kitrosser and B.W. Reinisch (P.I.)

1. Objective

The objective of this TRN was to operate a Digisonde 256 at Bermuda NAS using the lowest possible power level consistent with good data. The goal is to locate a Digisonde 256 permanently at that location, requiring low RFI to other users of the HF band. The data from this site are needed to provide input to the OTH-B radar for Sector 3 operation. This objective was to be accomplished through performance of the following tasks:

- a. Preparation for shipment and shipment to Bermuda NAS of one trailer-installed Digisonde 256 ionospheric sounder system. The contractor provided insurance coverage for the entire system for the total time the system was away from its facility;
- b. Selection of an acceptable site and set-up and check-out of the system. Operation of the system for two weeks, collecting data as per the test plan provided by the OTH-B Program Office; and
- c. Preparation for shipment and shipment of the system back to the University of Lowell and refurbishment of the system to restore it to its original performance specifications.

2. Activities

The initial task under this TRN was preparation and shipment of the Digisonde 256 to Bermuda NAS. The "Bermuda" Digisonde 256 was tested thoroughly prior to packing for transport to Bermuda. Based on our experience in shipping the Digisonde in the equipment trailer, the equipment racks were placed on 2" x 4" blocking and secured with aircraft loading tiedowns to prevent damage to the trailer floor and to keep the equipment in place during shipment. In addition, internal bracing were added inside the equipment trailer to prevent collapse of the trailer walls during ocean shipping. The TCI 613F transmit antenna was packed in a shipping crate and secured within the equipment trailer for transport to Bermuda.

It was determined that transport to Bermuda on a Navy-contracted vessel was subject to delays because of the transport of higher priority cargo. After coordination with the OTH-B Program Office, it was decided to ship the trailer and equipment secured therein by way of a commercial vessel. Overland shipment was arranged to New York City. The trailer with equipment was placed on a commercial ship and received in Bermuda on 26 August 1987.

Under the second task of this TRN, ULCAR was to support the site selection, set up and check out the system, and operate the equipment for a two-week period. An ULCAR senior engineer was a member of the test-site selection team. The test-site survey and selection took place in Bermuda 23-28 August 1987. The test site selected required approximately 1600 feet of cable from the digisonde transmitter to the transmit antenna. This distance necessitated the use of a lower-loss cable than the RG-213 coaxial cable used for installation with antenna separations on the order of 500 feet. The cable selected for Bermuda was Andrews Heliac LDF-4-50A-104, one-half inch diameter, saturated cable suitable for direct burial. This cable was available (two-week delivery) in 2000 foot lengths for approximately \$1.75/foot. The transmission loss is 0.211 dB/100' at 10 MHz and 0.369 dB/100' at 30 MHz.

Due to delays in scheduling the test period, which were beyond the control of ULCAR, the system set-up and check-out as well as the two-week test period were not conducted under this TRN; however, the testing and system set-up were conducted under TRN 20.

Under the third task of this TRN, ULCAR was to return the equipment to Lowell for refurbishment upon completion of the second task under this TRN. As a result of the second task being postponed, this task as well was not accomplished under this TRN.

3. Results

Evaluation of the mission requirements in support of the OTH-B radar testing/support program further strengthened the need for successfully deploying the Digisonde 256 at the Bermuda NAS. The accomplishments under this TRN established the deployment and siting of the Digisonde 256.

TRN 20: Bermuda Ionosonde Tests in Support of OTH-B
Dates: 2 November 1987 through 15 March 1988
Personnel: K. Bibl, D.F. Kitrosser, and B.W. Reinisch (P.I.)

1. Objective

The objective of this TRN was to operate a Digisonde 256 at Bermuda NAS using the lowest possible power level consistent with good data. The goal is to locate permanently a Digisonde 256 at that location, requiring low RFI to other users of the HF band. The data from this site are needed to provide input to the OTH-B radar for Sector 3 operation. This objective was to be accomplished through performance of the following tasks:

- a. Set-up and check-out of a trailer-installed Digisonde 256 ionospheric sounder. Deployment of seven-antenna receive arrays in assigned area. Operation of the system for two weeks collecting data as per the test plan provided by the OTH-B Program Office;
- b. Preparation for shipment and shipment of the system back to the University of Lowell and refurbishment of the system as required to restore it to its original performance specifications; and
- c. Analysis of the data taken during the tests.

2. Activities

The initial task under this TRN was to set up and check out the Digisonde 256 shipped to Bermuda under TRN 11, deploy the seven receive antennas, and operate the system for two weeks in accordance with the test plan provided by the OTH-B Program Office.

Installation of the trailer and seven receive antennas was accomplished by two ULCAR engineers in October 1987. The site selected for the Digisonde trailer was next to the water catchment, with placement of the receive antennas on top of the catchment providing a nearly level antenna array and allowing use of the standard 500-foot receive-antenna cables. As part of the system set-up, a TCI 613 twin-tower transmit antenna was installed by SRI International in lieu of the standard TCI 613F single-tower transmit antenna provided as part of the AWS DISS configuration. The TCI 613F sent as part of the Digisonde shipment was returned to the University of Lowell for storage.

During November 1987, a two-and-one-half-week test campaign was conducted under the supervision of SRI International. During the test campaign, ULCAR operated the Digisonde in normal sweep modes and fixed-frequency modes. Frequency-dependent attenuators were inserted between transmitter stages to keep the final transmitter output power to the antenna cable to less than 100-watts peak for frequencies below 10 MHz and below 200-watts peak between 10 MHz and 15 MHz.

On completion of the low-power testing, evaluation of the performance of ARTIST under low-power conditions was conducted using 611 ionograms that were taken during the test period.

The 611 ionograms were scaled manually for f_oF_2 using URSI guidelines. The ARTIST f_oF_2 values then were compared with the manually scaled values. More than 96% of the ARTIST f_oF_2 values were within ± 0.5 MHz of the manual scalings.

Details of the Bermuda Digisonde 256 deployment, test, and data analysis were presented in Interim Technical Report, "Bermuda Ionosonde Tests in Support of OTH-B," David F. Kitrosser *et al*, July 1988, subsequently published as Scientific Report No. 11, *GL-TR-89-0182*.

3. Results

Deployment and initial system checkout and calibration of the Digisonde 256 verified that no system degradation resulted from shipment and that all system functions were operational. Upon completion of the low-power testing and subsequent evaluation of the validity of ARTIST automatic scaling, operation at this low power was determined not to degrade the digisonde from fulfilling its mission requirements. However, even with the low transmitter power, interference with other HF users was noted, requiring further evaluation.

TRN 24: Bermuda Ionosonde Tests in Support of OTH-B

Dates: 22 December 1987 through 30 September 1988

Personnel: B.W. Reinisch (P.I.)

1. Objectives

The objectives of this TRN were to support the GL efforts during OTH radar tests, including evaluation of selected radar functions, to provide analysis reports and radar studies, and to perform interference tests at Bermuda NAS so that a sounder may be operated permanently at that location. These objectives were to be accomplished through performance of the following tasks:

- a. Operation of the Digisonde 256 at Bermuda NAS for a period of twenty days as per the test plan provided by the OTH Program Office;
- b. Provision for remote control of the Digisonde 256 and of low-loss cable to connect the transmitter to the antenna at Bermuda NAS;
- c. Provision of a flight-qualified Mission Director and one flight-qualified scientist or engineer for OTH as well as for GL research flights; and
- d. Use of various digisonde data to characterize propagation conditions, assess frequency management, and evaluate performance of OTH environmental-assessment software.

2. Activities

The initial task under this TRN was to support the low-power testing per the OTH Program Office Test Plan for the Bermuda NAS Digisonde 256. Due to the late start date of this TRN, the testing was conducted under TRN 20. However, as a result of this test campaign, the primary interference concern, Canadian Forces equipment at Daniel's Head, found no conflicts

with operation of the digisonde under the reduced-power conditions and with the deployment of a standard AWS remote terminal and modem to facilitate shutdown of the digisonde should interference conditions arise. Interference complaints were registered, however, by the nearby Anti-Submarine Warfare Operations Center (ASWOC). An issue undisclosed during the site survey was ASWOC use of HF communications to low-flying aircraft. Further examination revealed that the digisonde transmit antenna was installed approximately 400 feet from the ASWOC receive antenna.

To reduce the level of interference on the ASWOC equipment, ULCAR undertook three trips to Bermuda during December 1987 and January 1988. The initial trip was to install and test a passive amplitude clipper at the front end of the ASWOC receivers. This approach, although partially successful, did not fully rectify the observed interference. The second trip proved successful, with installation and testing of two active clippers placed at the ASWOC receivers with a blanking pulse supplied from the digisonde transmitter (located 700 feet away) and provision of an AWS remote terminal set at the ASWOC facility to permit shutdown of the digisonde should interference arise. The third trip was to install six more production versions of the active clipper identical to those installed during the second trip. At that time the ASWOC personnel seemed satisfied with the low-power operation of the Digisonde 256.

Details of the Bermuda Digisonde 256 blanker/clipper deployment are presented in Interim Technical Report, "Bermuda Ionosonde Tests in Support of OTH-B," David F. Kitrosser *et al*, July 1988 subsequently published as Scientific Report No. 11, *GL-TR-89-0182*.

The third task under this TRN was to provide a flight-qualified Mission Director and a flight-qualified scientist or engineer onboard the AIO in support of the OTH program and GL research flights. In early December 1987, the AIO was used as a dedicated target for performance testing of the OTH-B East Coast Radar System (ECRS). The primary goal of the test flights was calibration of the SRI International (SRII) target emulator. A secondary goal was collection of an ionospheric propagation database suitable for further development of analysis procedures to test and evaluate performance of environmental-assessment software and radar frequency management procedures. Results of these flights were documented in Interim Technical Report, "East Coast Radar System OTH-B Propagation Analysis Puerto Rico Round Robin Aircraft Flights," Gary S. Sales *et al*, August 1988. A second flight program in support of the OTH-B radar test program, initially scheduled for performance under this TRN, was delayed to November 1988 to mesh better with the overall test program.

The fourth task under this TRN was to evaluate the OTH environmental assessment software. This task was completed with the submission of Chapter 4.0 to the OTH Handbook, Interim Technical Report, "High Frequency (HF) Radiowave Propagation," Gary S. Sales, March 1989.

3. Results

The Bermuda Digisonde has verified compatibility with the HF user environment located at Bermuda NAS, given implementation of the production clippers and set-up of remote terminal

at the two sites of potential interference. Completion of this TRN should satisfy the siting requirements in support of long-term deployment approval.

The Puerto Rico flights raised some interesting problems in analysis of the propagation data. The effects of gradients became very apparent, and the requirement for a midpath vertical sounder to act as a control on the experiment was demonstrated clearly. We developed a method of analysis that was used to determine the relative roles of the changing ionosphere as measured by the f_oF_2 and the changing position of the AIO on the observed MOF variations.

The final chapter of the Handbook was submitted for approval under this task. Again, we believe this document will serve the people who must operate the OTH radars with little background in ionospheric physics or HF radiowave propagation.

I. MULTIPATH MITIGATION IN MEASUREMENTS OF TOTAL ELECTRON CONTENT (TEC) USING SIGNALS FROM THE GLOBAL POSITIONING SYSTEM (GPS)

Performing Organization: NWRA

TRN 13: Studies of Multipath Mitigation for TEC Measurements from GPS

Dates: 17 June through 30 September 1987

Personnel: C.C. Andreasen, R.M. Bussey, M.J. Klein, J.M. Lansinger (P.I.), and L.E. Piper

1. Objective

The objective of this TRN was to improve the accuracy of TEC measurements using GPS, in support of Air Weather Service acquisition of a worldwide Transionspheric Sensing System (TISS), which will measure TEC and other parameters of the transionospheric propagation channel operationally using GPS.

2. Activities

Determination of TEC by measurement of the differential group delay (DGD) between the two L-band signals transmitted from GPS satellites can be degraded by multipath reflections from the ground and from other objects near the receiving antenna. Under this TRN, we evaluated the multipath improvement available from judicious antenna selection and siting and developed an algorithm for software mitigation of multipath effects. The software method employs measurements of differential carrier phase (DCP) to remove or minimize multipath effects on concurrently collected DGD data. The former yields a very precise measure of relative change in TEC, but it lacks the absolute reference available in the latter.

Personnel of GL/LIS had postulated that DGD measurements of TEC free of multipath effects could be reconstructed from DCP data by applying statistical methods to the former to derive an optimum reference constant for the latter and then applying that constant to the DCP to create a new DGD data set. We devised a procedure to do so and evaluated it by means of the following steps:

- a. Selecting four pairs of data sets;
- b. Coding an algorithm to seek the least variable period of duration t in a given data set, where ' t ' was an input variable, and to generate a reference constant (offset) for the DCP data from the mean of the DGD data in that period;
- c. Tabulating the standard deviations of the DGD data, the values of the offset, and the times for up to ten of the least-variable periods for each of several different values of t (1.5 to 30 minutes);
- d. Studying the results to select the optimum t or to develop an algorithm for selecting t based on multipath characteristics;
- e. Generating multipath-corrected TEC from the DCP data referenced to DGD at the time of the latter's least variability, by means of an algorithm that automatically locates the best reference offset for the optimum t ; and
- f. Simulating real-time application of the preceding algorithm, and plotting the output to study the divergence between optimum and real-time results.

3. Results

Work under this TRN established two methods for substantially reducing multipath effects. First, judicious selection of a rooftop site, at least 40 feet from reflecting objects, for an antenna with suppressed low-angle sensitivity reduced multipath degradation from 40 to 4 TEC units (10^{16} electrons/m²). Second, a simple algorithm was developed for combining a DGD measurement, systematically selected for minimum multipath degradation, with DCP measurements essentially to eliminate, in real time after a half-hour initialization period, up to 15 units of multipath degradation from a developing TEC record. The same algorithm also reduced multipath errors of up to 25 TEC units to 3 units.

J. MEASUREMENTS OF TEC AND RADIOWAVE SCINTILLATION

Performing Organization: NWRA

TRN 14: Transionospheric Scintillation and TEC Studies

Dates: 7 July 1987 through 30 September 1988

Personnel: C.C. Andreasen, M.J. Klein, J.M. Lansinger (P.I.), and R.M. Bussey

TRN 23: Studies of Transionospheric Effects at Varying Latitude

Dates: 27 July through 30 September 1988

Personnel: C.C. Andreasen, M.J. Klein, J.M. Lansinger (P.I.), and R.M. Bussey

TRN 29: Studies of Ionospheric Electron-content Variations

Dates: 23 August through 31 December 1988

Personnel: C.C. Andreasen, M.J. Klein, J.M. Lansinger (P.I.), and R.M. Bussey

TRN 34: Studies of Ionospheric Effects During Solar Transition

Dates: 13 December 1988 through 30 September 1989

Personnel: C.C. Andreasen, M.J. Klein, and J.M. Lansinger (P.I.)

TRN 38: Studies of Ionospheric Effects Near Solar Maximum

Dates: 22 September through 3 December 1989

Personnel: C.C. Andreasen, M.J. Klein, and J.M. Lansinger (P.I.)

1. Objectives

The overall objective of the research supported by work under these TRNs is to advance understanding of TEC effects and scintillation on RF systems operating through the disturbed ionosphere, toward the ultimate end of improving the operation of transionospheric RF systems. Several specific TRN goals contributed to meeting this overall objective. The first was to assure reliable operation of ionospheric monitoring equipment at Thule, Greenland (geomagnetic invariant latitude = 85.7°). The second was acquisition and processing of high-quality data from Thule and from different latitude regions, to advance empirical characterization of the effects. The third was to advance understanding of the dependence of TEC variation on solar activity and elevation angle. The final one was to advance capability to characterize the effects of signal-delay and signal-strength variation on transionospheric RF propagation during periods of rapidly increasing solar activity, including the peak annual period near solar maximum.

2. Activities

Under these TRNs, NWRA provided engineering and technical support for the operation, maintenance, and enhancement of GPS data-collection systems located at Thule, Greenland, and Hanscom Field, MA. This work included expansion of the Thule observations from single-receiver to two-receiver operation in June 1988. NWRA also deployed the GPS system normally located at Hanscom to Kwajalein, Marshall Islands, and operated it there during three weeks in August 1988 in conjunction with PEAK 88. In October 1989, NWRA personnel installed a four-satellite GPS receiver at Sondre Stromfjord, Greenland (geomagnetic invariant latitude = 73.9°), in preparation for the CEDAR HLPS-3 campaign. In addition NWRA personnel upgraded and enhanced software used in the acquisition and processing of TEC and scintillation data from the GPS receivers, and they organized and catalogued tapes and charts from the acquisition sites. In addition to the excursion to Kwajalein, the work entailed one-week to two-week trips to Thule every two to three months. Between trips, troubleshooting and instruction of the Danish on-site technicians were conducted by telephone. Enhancement of the data-acquisition software included a choice of operator instructions in Danish as an alternative to English.

Improvement of the primary analysis software included addition of the multipath-correction algorithm developed under TRN 13. In addition, procedures were established for the generation of "quick-look" data summaries. An activity quantifier was established whereby hourly activity levels in GPS TEC measurements and amplitude scintillation, measured by means of the 250-MHz signal from a polar beacon satellite, were tabulated. Analysis involved statistical evaluation of valid database entries. This required development of a set of statistical-analysis programs written in DBASE III for use on a Zenith PC.

3. Results and Conclusions

Analysis of data collected at Thule from October 1987 through March 1988 demonstrated a direct relationship between TEC enhancement and scintillation activity. Fade-depth statistics during that period were compared with similar measurements from near the peak of the previous solar-activity cycle. Fade depths experienced during active periods in the winter of 1987-88 were less than those encountered during the quietest month near solar maximum. Both TEC and scintillation activity levels experienced during October and November of 1988, when the mean sunspot number (SSN) was 125, were generally increased over those for the same period a year earlier, when SSN had ranged from 27 to 76. This behavior was as expected for scintillation, but polar-cap TEC variation had not been measured during approach to solar maximum. The five most severe periods of TEC variation in October 1988 included numerous excursions in excess of 20 units, about twice the magnitude of those in October 1987. Observations have continued at Thule. The data collected between October 1988 and March 1989 show a dramatic increase in both activity level and probability of occurrence. The 1988-89 data disclose TEC variations whose magnitude typically is more than triple that of the previous year. Observations continued at Hanscom, Thule, and Sondre Stromfjord under this contract through the end date of TRN 38 and are continuing there and in the Shetland Islands, Scotland, under separate funding.

K. IONOSPHERIC EFFECTS ON SPACE-BASED RADARS (SBRs)

Performing Organization: NWRA

TRN 15: Space-radar Ionospheric Effects Studies

Dates: 7 July 1987 through 28 February 1988

Personnel: E.J. Fremouw (P.I.) and J.A. Secan

1. Objectives

The objectives of this TRN were to advance understanding of ionospheric effects on SBRs and to identify areas of shortfall in analysis or data needed to meet design goals and to develop approaches for mitigating those shortfalls.

2. Activities

The Air Force and the Navy have considered development of SBRs for purposes of defense surveillance. System configurations considered included sufficiently low frequencies

and grazing angles and sufficiently large apertures (synthetic or otherwise) to require consideration of the effects of the ionosphere on the radar propagation path. Toward this end, GL hosted a workshop in which engineering organizations responsible for system design were brought together with research organizations active in identifying and characterizing ionospheric effects to assess the need for and the state of relevant knowledge. NWRA provided assistance to GL in organizing and conducting the workshop.

Among the potentially adverse effects considered at the workshop are those arising from refractive and diffractive forward scattering through narrow angles by plasma-density irregularities, collectively termed "radiowave scintillation." Under this TRN, we assessed the suitability and limitations of available computer models of scintillation and presented our assessment for discussion at the workshop.

3. Conclusions

Following the workshop, we reviewed and evaluated its results, concentrating on specific shortfalls in models and in analysis of existing data and on needs for specific new data sets. The three major conclusions of that review are as follows:

- a. Faraday rotation must be considered at L Band, and linear polarization should be avoided at lower frequencies;
- b. The strength, spatial spectrum (which dictates the backscatter frequency dependence), and degree of magnetic-field alignment of plasma-density fine structure in the F layer, which may be capable of producing radar clutter, should be ascertained, as should the doppler spectrum of the backscatter that it would produce; and
- c. Scintillation is the most likely threat to SBR performance, especially at low frequencies and/or low grazing angles on the ionosphere (or on elongation axes of the scattering structures).

Foremost among the shortfalls in the most widely used scintillation model, WBMOD, were the following:

- a. The complex signal's space-and-frequency and time-and-frequency mutual coherence functions were not calculated;
- b. The seasonal/longitudinal dependence of scintillation at high latitudes is not included; and
- c. Only a single regime was employed in the power-law spatial spectrum describing scintillation-producing irregularities.

A two-regime spectrum now has been incorporated into WBMOD, as a result of the Workshop. The seasonal/longitudinal deficiency was to be remedied in on-going work, but funding for that work was terminated prematurely. We recommended that the width of the time-and-frequency mutual coherence function (i.e., the signal ambiguity function) in time (and/or

space) and frequency (and/or angle) be added to WBMOD. The temporal and spatial widths, t_0 and l_0 respectively, now have been added.

In addition, we noted one relevant shortcoming in propagation theories commonly employed to characterize and/or mitigate ionospheric effects. Ionospheric structures are almost always dealt with in one or the other of two scale-size limits. The structures are assumed to be either: (a) large enough that individually they extend completely through any region of irregular plasma density along the line of sight, in which case propagation through them is treated deterministically, or (b) small enough that any scattering layer is many irregularities thick along the line of sight, in which case statistical propagation theory is used. The former regime is usually thought of as the TEC regime and the latter as the scintillation regime.

Structures intermediate in size (tens of km) between the foregoing two limiting regimes are relevant to SBR performance (e.g., in the focusing and defocusing of synthetic-aperture antenna beams). The shortcoming is that propagation theories commonly used for synoptic purposes (as opposed to fundamental application of Maxwell's equations and/or the resulting wave equation to fully and specifically described media) do not treat them properly.

One practical result of the theory deficiency is that the variance of phase is taken to be proportional either to the incidence angle on the ionosphere (scintillation result) or to the square of that angle (TEC result). This difference can amount to almost an order-of-magnitude difference between the ratio of phase variance near the zenith and that at low elevation angles. Present synoptic theory does not treat the transition between these two results at intermediate scales.

Regarding data shortfalls, we pointed out that the greatest need is for an accurate assessment of the solar-cycle dependence of scintillation at equatorial, auroral, and, especially, polar-cap latitudes. We noted that observing programs are under way at high latitudes but that the deficiency is not being addressed at equatorial latitudes. As of this writing, it still is not.

Finally, we point out another shortcoming in use of scintillation models. Existing models fundamentally are climatological in nature, more suited to design studies and systems planning than to real-time use. Ionospheric and geomagnetic databases amenable to updating by means of real-time observations using operational satellites and ground-based facilities, however, do exist (e.g., at Global Weather Central of the Air Weather Service). Proper links between such databases and models such as WBMOD could render the combination suitable for real-time channel assessment and mitigation. One use of such a capability might be to determine appropriate times for employing methods described at the Workshop for reducing propagation-induced phase errors in coherent systems. These mitigation methods could be employed either in real time or, in some applications, retrospectively.

L. DATA-ACQUISITION AND ANALYSIS TOOLS FOR STUDIES OF METEOR-SCATTER PROPAGATION IN POLAR REGIONS

Performing Organization: ULCAR

TRN 16: Meteor-scatter Polar-ionospheric Propagation Studies Control-system Development and Data Analysis

Dates: 4 December 1987 through 31 January 1988

Personnel: J.E. Powers (co-P.I.) and J.A. Weitzen (co-P.I.)

1. Objectives

The objective of this TRN was to support GL studies of meteor-scatter propagation effects under severely disturbed ionospheric conditions through the development, implementation, and operation of data-acquisition and analysis techniques and tools. This objective was to be accomplished through the following tasks:

- a. Development and provision of continuing support for meteor-scatter data-analysis software to be implemented and operated on GL PC and VAX computer systems; and
- b. Provision of engineering and technical support to:
 - (1) Develop PC controller software and interface hardware for polar-cap meteor-scatter receiver/data-acquisition systems, and
 - (2) Support implementation of control and interface systems as required for data acquisition and analysis at Thule and Sondre Stromfjord, Greenland.

2. Activities

The initial task under this TRN was to continue support and development of the meteor-scatter data-analysis software. Efforts under the TRN were a continuation of the development plans initiated under TRN 19 for modification of the Autoclass 2.0 technique.

The second task under this TRN was to provide engineering and technical support for development and implementation of PC controller software and interface hardware for the Greenland meteor-scatter data-acquisition and analysis system. In March 1988 ULCAR personnel traveled to Thule AB, Greenland, to replace the error-prone InterDyne tape drive with a Kennedy 6455 tape drive. In addition, a new balanced-feed scheme was implemented to improve isolation of the horizontally and vertically polarized Yagi antennas. Results of the field-site testing are presented in Interim Technical Report, "Receiver System Control Development for the GL High Latitude Meteor-scatter Test Bed in Greenland," S. W. Li, September 1988, subsequently published as Scientific Report No. 16, *GL-TR-89-0193*.

3. Results

Improved control software for both the transmitter and receiver of the high-latitude system was developed. New data-analysis software to allow analysis of absorption events was developed.

TRN 19: Meteor-scatter Polar-ionospheric Propagation Studies Control-system Development and Data Analysis

Dates: 16 November through 31 December 1987

Personnel: E. Li, J.E. Powers (co-P.I.), and J.A. Weitzen (co-P.I.)

1. Objective

The objective of this TRN was to support GL studies of meteor-scatter propagation effects under severely disturbed ionospheric conditions through the development, implementation, and operation of data-acquisition and analysis techniques and tools. This objective was to be accomplished through the following tasks:

- a. Development and provision of continuing support for meteor-scatter data-analysis software to be implemented and operated on GL PC and VAX computer systems; and
- b. Provision of engineering and technical support to:
 - (1) Develop PC controller software and interface hardware for polar-cap meteor-scatter receiver/data-acquisition systems, and
 - (2) Support implementation of control and interface systems as required for data acquisition and analysis at Thule and Sondre Stromfjord, Greenland.

2. Activities

The initial task under this TRN was to continue support and development of the meteor-scatter data-analysis software for use on the GL PC and VAX computer system. With the deployment of the new PC-based meteor-scatter receiver and data-acquisition system, changes were necessitated in the data handling and analysis programs. Under this TRN and TRN 16, combined efforts between ULCAR and GL/LID were undertaken to develop quick-look data-handling routines to ensure data integrity. Development plans for modification to the Autoclass 2.0 technique were established.

The second task under this TRN was to provide engineering and technical support for development and implementation of PC controller software and interface hardware for the Greenland meteor-scatter data-acquisition and analysis system. This task was accomplished in two subtasks.

One subtask was modification of the controller/transmitter interface to allow control of up to eight transmitting frequencies and operational changes to the control algorithm, to improve the calibration sequence by providing additional information to the operator on the system status

when in this mode. Deployment of the updates to the meteor-scatter test bed was initially accomplished during a site visit by ULCAR personnel in November 1987. Debugging of the control algorithm commenced in January 1988 with a successful demonstration of all the functional operations conducted at GL/LID under simulated conditions. Details of this effort are presented in Final Test Report, "The Modification of the Real-time Software and Hardware Interface for a Meteor Burst Transmitter System," James E. Powers, February 1988.

The second subtask was development and deployment of the new meteor-scatter receive system located at Thule. Deployment of the new receive system and uninterruptible power supply was accomplished in November 1987. For the purpose of data comparison, the old receive system was kept operating on a temporary basis. With deployment of the receive system, six horizontal and vertical Yagi antennas at 35, 45, 65, 85, 104, and 147 MHz were set up, with reception successfully demonstrated. Additionally, a dial-up modem was established between the main site and the remote site a mile away. A successful demonstration was conducted through remote data retrieval of the receive system at Hanscom AFB via a remote terminal. Results of this subtask are presented in Interim Technical Report, "Receiver System Control Development for the GL High Latitude Meteor-scatter Test Bed in Greenland," S. W. Li, September 1988, subsequently published in Scientific Report No. 16, *GL-TR-89-0193*.

3. Results and Conclusion

Under this TRN, the new data acquisition system for the high-latitude meteor-scatter test bed was fielded, and testing of the system began. The new system allowed much more detailed analysis of data and provided a valuable resource for meteor-scatter researchers.

M. FORECASTING THE SPACE ENVIRONMENT

Performing Organization: ULCAR

TRN 22: Advanced Topics in Space Environmental Forecasting Course

Dates: 2 May through 15 July 1988

Personnel: A.L. Synder (P.I.)

1. Objective

The objective of this TRN was to train Air Force Global Weather Central (AFGWC) and Air Weather Service (AWS) personnel in various topics related to ionospheric effects on Air Force C3I systems. This objective was to be accomplished through performance of the following task:

Preparation and teaching of a three-week course entitled "Advanced Topics in Space Environmental Forecasting," the course to be given at AFGWC, Offutt AFB, Nebraska.

2. Activities

Under this task a four-week course in "Advanced Topics in Space Environmental Forecasting" was prepared and given at the AFGWC from 2 May 1988 through 27 May 1988. The course was presented in six-hour blocks, five days per week, with time split about equally between lecture/discussion and laboratory exercises. The exercises were centered around understanding the uses and interpretations of the data sources available to AFGWC. The course material and description were presented in Interim Technical Report, "Advanced Topics in Space Environmental Forecasting," Arnold L. Snyder, Jr., July 1988.

3. Results

The purpose of the course was to train AWS personnel in various topics related to space-environmental effects on Air Force systems. The course material was well received; however, it is recommended that, if the course is offered again, one day be devoted to a review of the principles of electricity and magnetism to provide a more uniform background for student understanding.

N. KINETICS OF ULTRAVIOLET EMISSIONS

Performing Organization: SAIC

TRN 30: Support for Studies of the Kinetics of Ultraviolet Emissions

Dates: 5 December 1988 through 30 September 1989

Personnel: A. Dentamaro, E. Szuszczewicz, and J. Thomas

1. Objective

The objective of this TRN was to aid in conducting studies under the GL/LIU basic-research effort in atmospheric ultraviolet processes.

2. Activities

This study involved two components:

- a. effects of vibrational excitation on rate parameters of atmospheric reactions; and
- b. laboratory and field experiments dedicated to understanding atmospheric radiation in the ultraviolet.

In the first activity, v -level specific bimolecular rate constants for the reaction of $N_2(A^3\Sigma_u, 4 \leq v \leq 6)$ were measured for NO. The non-thermal NO(A, u') product distribution was investigated using a 2.2 m spectrograph.

In the second activity, field experiments were performed on Santa Ynez Mountain during the week of 18-25 January 1989. The observation point was 4133 feet above sea level, and weather conditions were fairly good for much of the experiment period. An 18-in Cassegrain telescope and UV imaging system was used to observe and record starlight in the wavelength

range 3000-3700 Å to provide real-time sampling of the atmosphere and allow an accurate study of remote UV sources of unknown intensity. The spatial dependence for the transmission of radiation through the atmosphere was calculated using the LOWTRAN 6 computer code, and the results were compared to data from various UV-emitting stars. Variations in the atmosphere were seen to depend strongly on aerosol concentrations. Ground-level photometer measurements of extinction coefficients were extrapolated to yield atmospheric visibility profiles for the observation point.

3. Conclusion

The first segment of the project measured rate constants for $v = 4$ to 6. A previous study using simple and direct techniques observed an increase in k with v for $v = 0$ to 3 followed by an apparent leveling off in k for $v = 3$ to 6. Taking an average of the rate constants for $v = 3$ to 6, a value of $(11.1 \pm 0.8) \times 10^{-11} \text{cm}^3 \text{sec}^{-1}/\text{molecule}$ was obtained, approximately 40% of gas kinetic. An average of the measurements for $v = 4$ to 6 yielded $(10.7 \pm 0.7) \times 10^{-11} \text{cm}^3 \text{sec}^{-1}/\text{molecule}$, in very good agreement with the previous study. This confirmed that the fluid dynamics in the newly constructed RPDR (rapidly-pumped discharge-flow reactor) had been characterized properly.

The results of field measurements in the second activity were encouraging, with the measurements of meteorological range most accurate for $\theta > 60^\circ$. Furthermore, measurements at lower angles provided the advantage of allowing the observer some idea of the error involved in the measurements for any spatial point, and the overall results gave insight into problems in measurements of UV radiation through the atmosphere.

O. A DATA STORAGE AND RETRIEVAL SYSTEM BASED ON OPTICAL-DISK TECHNOLOGY

Performing Organization: NWRA

TRN 35: Studies on Implementation of an Optical-disk-based System for Storage and Retrieval of Polar BEAR Data

Dates: 5 May through 30 November 1989

Personnel: R.M. Bussey (P.I.), F.J. LeBlanc, and E.J. Fremouw

1. Objective

This TRN was let in furtherance of the objective of TRN 33, namely to aid GL/LIU in deriving useful products from the AIRS imager experimental data on a timely basis.

2. Activities

A conceptual design study for a system that would permit rapid retrieval of the voluminous database from AIRS and other instruments on the Polar BEAR satellite was conducted under TRN 33. More than 6000 AIRS images, consisting of sets from up to four different wavelengths, were recorded from Polar BEAR. The volume of raw AIRS pixel and housekeep-

ing data approximates 500 megabytes (Mb). Other data necessary to process the images, such as satellite ephemeris information, sun-sensor data, and vector-magnetometer data add approximately another 300 Mb. The sun-sensor and vector-magnetometer data are used to determine spacecraft attitude, which is required for geometric correction and registration of the images. The additional image file descriptors and computer operating-system overhead result in a data volume approaching a gigabyte. In view of the size of this database and the desire for rapid random access to particular images and auxiliary information, NWRA recommended storage on rewriteable optical disks and quick-look display by means of the ITTI FG100/AT graphics board. To ensure portability from one computer to another, we also recommended an alternative (coarser-resolution) display by means of standard EGA.

3. Results

Under this TRN, NWRA implemented the conceptual design created under TRN 33 and developed a demonstration database of AIRS images. Investigation of available optical-disk technology resulted in a decision to employ a magneto-optic drive, which conforms to the ANSI/ISO physical format. It is based on the Sony Rewriteable Optical Disk (Model SMO-D501). The data files are written in the Hierarchical Data Format developed by the National Center for Supercomputing at the University of Illinois, Urbana-Champaign.

The demonstration database consists of over 6000 images and auxiliary information collected from Polar BEAR launch on 13 November 1986 through March 1987. It occupies three sides of optical-disk cartridges, each side having a formatted capacity of approximately 285 Mb. In addition to the images (or spectrophotometer data, depending upon AIRS' operating mode), the database contains the following information:

- Receiving-station latitude, longitude, and altitude;
- Satellite latitude, longitude, and altitude and the NORAD ephemeris elements used to determine them;
- Satellite roll, pitch, and yaw and the sun-sensor and vector-magnetometer data used to determine them;
- TEC on the radiowave path;
- VHF radiowave intensity and phase-scintillation indices (S_4 and σ_ϕ) calculated over half-overlapping 30-sec detrended and windowed data spans; and
- Latitude and longitude of the radiowave ionospheric penetration point (at 350 km altitude).

A small database of information about the images and the geophysical conditions existing at the time allows the scientist using the database to select a subset of images for review. A

simple graphic display of the images in this subset permits final selection of the images to receive detailed analysis.

P. MEASUREMENTS OF HIGH-LATITUDE IONOSPHERIC DRIFT

Performing Organization: ULCAR

TRN 37: Sondre Stromfjord Ionosphere-drift Measurements

Dates: 6 July through 30 September 1989

Personnel: G. Crowley, D.F. Kitrosser, W.S. Kuklinski, J.G. Moore, B.W. Reinisch, and G.S. Sales

1. Objectives

The objectives of this TRN were to provide scientific manpower to measure polar-region ionospheric-plasma convection (drift), calibrate the measurement system against incoherent-scatter radar measurements, interpret the data, and provide the results in a report. The objectives were to be accomplished through the following tasks:

- a. Provision of a scientist in the field of ionospheric physics to support drift measurements conducted by GL at Qaanaaq and Sondre Stromfjord, Greenland;
- b. Support of the deployment of a Digisonde 256 (AWS DISS version) at Sondre Stromfjord. Conduct of initial system calibration and collection of data during the Sondre Stromfjord Incoherent-Scatter Radar Drift-net Operation and during monthly regular World Days; and
- c. Analysis of Qaanaaq and Sondre Stromfjord drift data, interpreting them in the context of interplanetary/geophysical and incoherent-scatter radar data.

2. Activities

Under this TRN, ULCAR participated in deployment of a Digisonde 256 at Sondre Stromfjord during July 1989. After initial deployment, a calibration was conducted to confirm system operation and initiate data collection.

Following deployment and system calibration, an experimental campaign was conducted during the period 7 July through 11 July 1989. The purpose of the campaign was to study the slant E_s conditions sometimes observed in the polar cap under magnetically quiet conditions. Unfortunately, no slant E_s was observed; however, drift data were obtained continuously for the five-day period at both Sondre Stromfjord and Qaanaaq. Analysis and interpretation of these drift data in the context of interplanetary, geophysical and incoherent-scatter radar data was conducted and presented in Interim Technical Report, "Digisonde at Sondre Stromfjord to Monitor the Ionospheric Polar Cap and Cusp Region," Geoffrey Crowley *et al*, January 1990.

3. Results

The new Digisonde DGS 256 installed at Sondre Stromfjord during June 1989 is fully operational. The system has been calibrated, and it provided high-quality data for the five-day interval between 7-11 July 1989.

The drift mode interfered with local communications on certain frequencies and therefore had to be switched off. The drift-mode operation will be modified to avoid the most-important communication frequencies. Ionograms were collected during much of the interval from July - October 1989.

Quantitative validation of the digisonde-observed drifts by comparison with incoherent-scatter data was again thwarted. The drift and ionograms from Sondre Stromfjord generally show the kind of features expected. In particular, the instrument samples different parts of the convection pattern, including the polar cap, at different times of day.

Data from other stations will provide further details of convection behavior. Qaanaaq, Goose Bay, and Argentia are to be examined. Eventually, drift data from all the AF digisondes will be used as inputs to the AMIE (Assimilative Mapping of Ionospheric Electrodynamics) technique of Richmond and Kamide (1988) to derive global convection patterns.

IV. REPORTS, PAPERS, AND PRESENTATIONS

The following reports, papers, and presentations were prepared solely or in part under this contract:

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